THE ACCURACY OF A MODERN BALANCE AND SET OF WEIGHTS.

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IT would seem to be a matter of some interest to know just what may be expected of a good precision balance of modern construction, bought in open market, without any special requirements having been imposed on the maker or dealer. The construction, as regards material and workmanship, perhaps may be judged to some extent by general appearances to a critical observer, and by facility of adjustment and smoothness of operation. The excellence of the instrument in the precise determination of weights, depending largely on the equality of lengths of arms and smoothness of the sensibility curve, can be determined only by careful tests.

The balance chosen for the tests here reported is by Paul Bunge, Hamburg, and is of the type described in his catalogue as number "0." It is also described in Watson's Physics (pp. 109, 110). The length of the beam is nominally 13 cm., and is of the short-arm, high-stayed triangle form. The rider scale, also 13 cm. long, extends along the entire front of the beam, and is numbered from 0 to 10, each tenth of the length being subdivided into 10 parts, or 100 in all. The rider weighs nominally 5 mg., and is to be at the "0," beam horizontal and no load. The pointer is long, 25.5 cm. from the central knife edge.

As ordinarily used the balance has the usual sensitiveness of $\frac{1}{10}$ mg. but a delicacy of $\frac{1}{100}$ mg. may be readily secured by placing a small cylindrical weight on the top of an arm extending vertically upward back of the center of the beam. The swings are then read by a microscope extending through the front of the case at an angle of forty-five degrees and focused on a small ivory scale attached to the pointer about 4 cm. from its lower end. This scale is 10 mm. long and is divided into 100 parts, microscopic figures being placed at each tenth division. This fine scale, in addition to its use in very precise weighings with the fine adjustment, enables one to make more accurate determinations with the ordinary $\frac{1}{10}$ mg. sensitiveness than is possible by reading the swings in the ordinary way on the coarse scale. The vibration time being, of course, the same, readings may be made with almost as great facility through the microscope as on the coarse scale.

The testing of the balance and weights has thus far consisted of the following determinations:

1. The testing of the weights by the Bureau of Standards.
2. The sensibility curve.
3. The values of certain weights from laboratory sets, both for purposes of calibration and to determine how closely values may be repeated.
4. The ratio of the arms.

The details of the above determinations are as follows:

1. *Testing of the Weights.*—The weights were also by Bunge, supplied with the balance, and of the usual type. They were sent to the Bureau of Standards for comparison with the United States standards. The following is taken direct from the certificate of the bureau:

"The weights designated below have been compared with the United States standards and have the following corrections:

Designation.	*Correction.*	*Designation.*	*Correction.*
100 grams	−0.4 mg.	500 mg	−0.015 mg.
50 "	−0.5 "	200 "	−0.034 "
20 "	−0.32 "	100^1 "	−0.068 "
10^1 "	−0.22 "	100^2 "	−0.034 "
10^2 "	−0.11 "	50 "	+0.070 "
5 "	−0.31 "	20 "	−0.013 "
2^1 "	−0.12 "	10^1 "	−0.027 "
2^2 "	−0.09 "	10^2 "	+0.012 "
1 "	−0.00 "	5^1 " rider	+0 076 "
		5^2 " "	+0.080 "

"A (+) correction means that the weight is heavier than the nominal value; a (—) correction that it is lighter by the amount indicated. When applied to the nominal value of a weight, the correction will give its mass referred to the international kilogram."

2. *Sensibility Curve.*—Readings for the sensibility curve were made in the usual way, using loads of even numbers of grams from 0 to 200. The microscopic scale was used, sensibility being taken as the number of divisions displacement for one mg. additional load. In the tabulation of results, "L" indicates the load; "S," divisions displacement per mg.; "M," means of five preceding values of "S." The values of "S" are the means of independent determinations by each of the authors of this paper. However, but one set of values was gotten by each observer, and it is probable that the irregularities are due quite as much, or more, to accidents of observation as to lack of uniform action of the balance. The curve traced from the values of "S" given shows a rather rapid drop from 0 to about 30, a tolerably uniform value slightly below 5 from 30 to about 130, and from this point to the maximum load

of 200 the gradually decreasing value indicates, it would seem quite clearly, the lowering of the centroid by the flexure of the beam under the increasing load. Perhaps the lowering of the values from 0 to 30 may be explained by a straightening out of the stays of the beam, or at least a drawing taut. It is quite likely that, owing to the form of the beam already mentioned, that of a triangle, the knife edges might be drawn slightly out of line with no load on the beam. After this the beam remains straight to about 130 gms. load, when it begins to bend slightly under the increased strain. Such an explanation would account for the three parts of the curve which appear rather marked. The data for the curve follow:

L.	*S.*	*M.*	*L.*	*S.*	*M.*	*L.*	*S.*	*M.*	*L.*	*S.*	*M.*
0	5.4		50	4.9		100	5.0		150	4.8	
2	5.2		52	5.0		102	4.9		152	4.8	
4	5.2		54	5.0		104	4.8		154	4.8	
6	5.2		56	5.0		106	4.9		156	4.8	
8	5.0	5.20	58	5.0	4.98	108	5.0	4.92	158	4.8	4.80
10	5.1		60	5.0		110	4.9		160	5.1	
12	5.1		62	4.9		112	5.0		162	4.9	
14	5.3		64	4.9		114	5.0		164	4.7	
16	5.1		66	4.9		116	4.9		166	5.0	
18	5.0	5.12	68	5.1	4.96	118	4.9	4.94	168	4.9	4.92
20	5.3		70	4.9		120	5.0		170	4.8	
22	5.1		72	4.8		122	4.9		172	4.8	
24	5.0		74	5.2		124	4.9		174	4.8	
26	5.1		76	4.9		126	5.0		176	4.7	
28	5.0	5.10	78	4.9	4.94	128	4.9	4.94	178	4.7	4.76
30	4.8		80	4.9		130	4.9		180	4.7	
32	5.2		82	4.9		132	4.9		182	4.6	
34	5.0		84	5.0		134	4.9		184	4.6	
36	4.9		86	4.7		136	4.8		186	4.6	
38	4.9	4.96	88	5.0	4.90	138	4.8	4.86	188	4.8	4.66
40	5.0		90	4.9		140	4.8		190	4.7	
42	5.0		92	4.9		142	4.8		192	4.7	
44	5.2		94	5.0		144	4.8		194	4.7	
46	4.9		96	4.9		146	4.8		196	4.7	
48	5.1	5.04	98	5.0	4.94	148	4.8	4.80	198	4.7	4.70
50	4.9		100	5.0		150	4.8		200	4.7	

3. *Values of Laboratory Weights.*—The weights were as follows: 1, 20, 50 and 100 gms.; combinations were also made to give 120, 150 and 170 gms. The headings of the columns explain the data.

Nominal values.	Determined weights.		Differences.
	W.	McF.	
gm.	*gm.*	*gm.*	*mg.*
1	0.99984	0.99983	0.01
20	20.00065	20.00061	0.04
50	49.99854	49.99852	0.02
100	99.99991	99.99992	0.01
120	120.00051	120.00048	0.03
150	149.99835	149.99842	0.07
170	169.99907	169.99903	0.04

Each weight given is the means of weighings right and left—not the square root of the product. But one determination of each weight was made by each observer. The adjustment of the balance was for the lower sensitiveness of $\frac{1}{10}$ mg. It was planned to make determinations for a sensitiveness of $\frac{1}{100}$ also, but lack of time prevented. All values have been carried out at least one place further than shown in the above figures.

4. *Ratio of the Arms.*—The ratio of the arms has been computed from the values from 20 to 170, with the results given:

Load.	Ratio of arms, L/R.	
	W.	McF.
20	0.999995	0.999997
50	7	7
100	6	7
120	8	8
150	5	8
170	8	8
	0.9999965	0.9999975

Mean value of L/R, 0.999997.

Further determinations are desired, especially for the higher sensitiveness, no values of which are given, and but few of which have been secured.

The weighings were all made without any precautions to secure dryness of the air in the balance case.